Nordic Hydrology, 1982, 205-212

Assessment of »True« Variability of Small Rainfall Events in a Small Mountainous Watershed in the Summer

Lawrence C. Nkemdirim
Dept. of Geography, University of Calgary,
Alta T2N 1N4, Canada

Brian D. Meller
Monenco Consultants Ltd., Calgary, Alta T2G, OP6, Canada

The standard error of mean areal rainfall was calculated for various densities of rain gauge network in a small mountainous watershed in the summer of 1978. It is shown that a) the optimum gauge density required to assess mean rainfall is about 3 gauges/km^2; b) the »true« variability in the spatial distribution of rainfall decreases with increasing rainfall amount; and c) the relationship between »true« variability and rainfall volume is linear in that watershed.

Introduction

The assessment of mean rainfall in areas of pronounced topography has always been of interest to hydrologists. Early research on the effect of orography on precipitation considered the importance of elevation on rainfall (Lee 1911, Price and Evans 1937). Spreen (1947) and Burns (1953) discussed the influence of physiographic variables on rainfall. However, although it has long been recognised that the best assessment of mean rainfall in mountain regions can be obtained by installing high rain gauge densities, there have been very few experiments conducted to demonstrate how large a network should be for a realistic assessment of mean rainfall and the spatial variability associated with rainfall in mountain regions. It is partly to fill this gap in our knowledge that the experiment reported below was conducted.

In the summer of 1978, a dense rain gauge network was installed in a small watershed located in the mountainous Crowsnest Pass region of southeastern British Columbia as part of a hydrologic study. A component of the study involved the statistical assessment of the network required to realistically measure the spatial variation of summer rainfall events in the watershed. This analysis facilitated the determination of the optimum rain gauge density for the assessment of areal rainfall for low intensity rainfall events (less than 10 mm).

The Study Area

The drainage basin is located at Coal Mountain in the Crowsnest Pass region of Canada's British Columbia (Fig. 1). Geologically, the study area is situated in the Eastern Cordillera, a geological region extending from the Alberta plains across the foothills of the Rockies, and into the mountains of the Rocky mountain Trench. Rock within this area is strongly folded and thrust-faulted with regional structure dipping westerly. It is an extremely rugged region. Slopes are steep, averaging 44 percent. Average elevation change from 1,525 m to 2,075 m a.s.l.

Method

The rain gauge network consisted of 2 automatic and 12 standard gauges distributed randomly within the basin with adjustment made to accommodate the distribution of elevation inside the watershed (Nkemdirim 1981). Accessibility was also a factor in locating the gauges. Gauges were distributed at intervals averaging about 30 m. The lowest level at which a gauge was located was 1,500 m. The highest location was at 1,900 m (Fig. 2). For this study, the automatic gauges were treated as part of the standard gauge network and calibrated accordingly. This inclusion brought the overall rain gauge density to 4.8 gauges per km^2.

To assess the adequacy of the network, the standard error of the mean areal rainfall was calculated for a given storm using measurements from all the gauges. This static was then successively recalculated for the same storm using progressively smaller number of readings. The reduced gauge network was achieved by randomly removing 1,2, ... n gauges sequentially from the network until only data from two gauges remained. The data points removed for each experiment were restored before the next experiment was conducted. This procedure was applied to six rainfall events of varying intensity and duration.

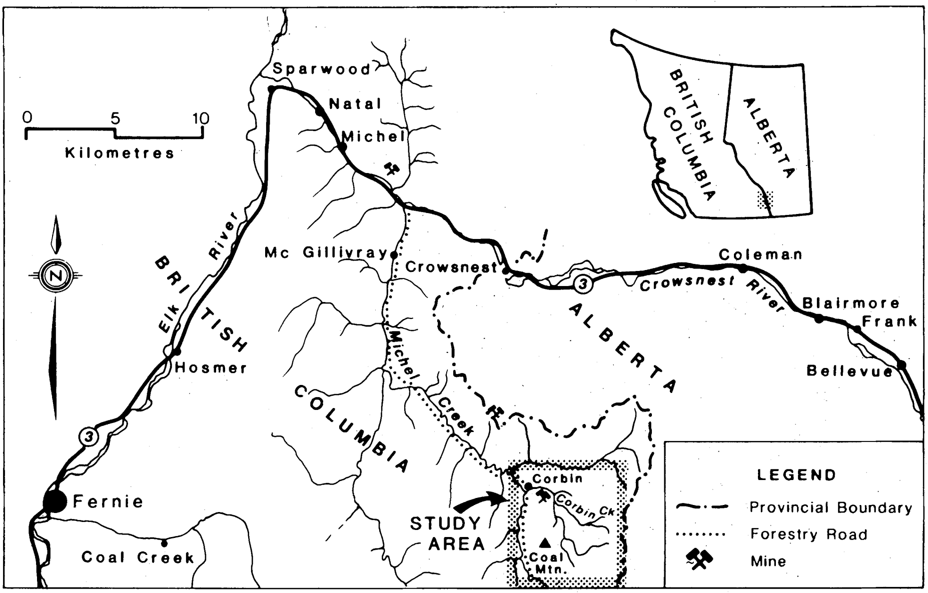

Fig. 1. Location of study area

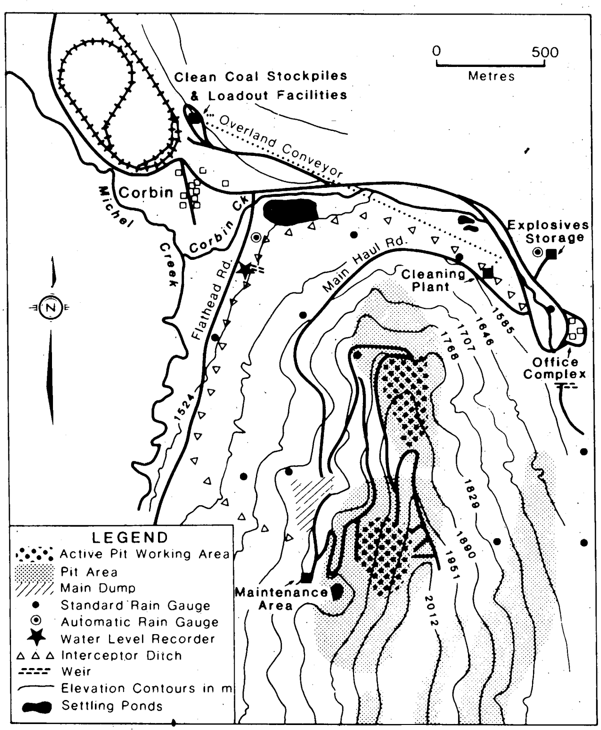

Fig. 2. Distribution of rain gauges.

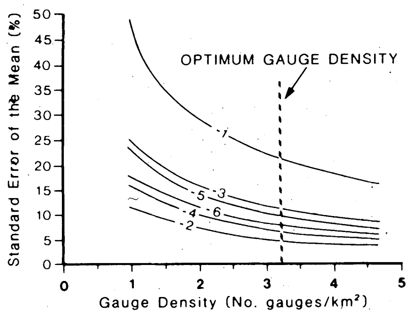

Fig. 3.
Relationship of standard error of the mean to gauge density for six storm events.

On the assumption that each point measurement represented an areal sample, the error of estimate of the mean rainfall at each trial of the experiment was obtained from the equation

$$\lambda \equiv \sigma (n)^{-\frac{1}{2}}$$

where λ is the 'error' of estimate, σ, the standard deviation of the point measurements and n, the number of gauges employed at the trial.

λ was plotted against the corresponding gauge density, n_d and a regression equation relating the two variables was obtained for each of the six events (Fig. 3). The value of n_d at the point where the slope of the curve approached zero was taken as the optimum gauge density because beyond that point the addition of more gauges did not significantly improve the estimate of the mean.

Results

Listed in Table 1 are the duration of each rainfall event, its mean depth over the watershed, the regression equation of λ on n_d, and the correlation coefficient between the two variables.

The slope of the curves was almost identical. This suggests that the process for error reduction is similar in all cases. Error is reduced by increasing the gauge density. However, the displacement of the curves from the origin varied widely in response to differences in duration and intensity of the events. In general, the standard error increased as the rainfall amount and/or duration decreased. This suggests that more rain gauges are required for the assessment of mean areal rainfall for storms of short duration or low intensity than for larger or longer duration storms (Eagleson 1967). This is to be expected since larger and persistent storms tend to display a more uniform areal distribution than small and short duration rainfall events.

Table 1 – Rainfall duration, mean depth, regression equation of error on gauge density, and correlation coefficient

Storm	Duration (hrs)	Mean Rainfall (mm)	Regression Equation Standard error (λ) against network density (n_d)	$r(\lambda, n_d)$
1	3	1.8	S.E. $\equiv 76.58 n_d^{-0.63}$	.97
2	9	6.6	S.E. $\equiv 17.76 n_d^{-0.64}$	.95
3	2	1.1	S.E. $\equiv 38.75 n_d^{-0.62}$	.95
4	8	4.7	S.E. $\equiv 25.13 n_d^{-0.60}$	.97
5	5	5.7	S.E. $\equiv 33.73 n_d^{-0.63}$	.95
6	5	6.2	S.E. $\equiv 27.96 n_d^{-0.62}$	.95

Based on the criteria established above, the optimum gauge density for the basin varied from 2.4 gauges/km^2 for the largest storm to 4.2 gauges/km^2 for the smallest event. The mean density for all storms is about 3 gauges/km^2. For the watershed, these numbers suggest that the optimum gauge density for realistic assessment of mean areal rainfall for major frontal precipitation may be less than the observed lower limit. However, it is doubtful that error can be significantly reduced for storms smaller than the smallest event in the study by increasing the density of the network.

Discussion

»Error« in the assessment of mean areal rainfall from point measurements may be divided into three broad categories, namely; a) random error, b) error due to inadequate gauge network, and c) 'error' due to variability inherent in the distribution of storm rainfall.

The consistency in the size of the correlation coefficients between 'error' and gauge density (Table 1) suggests that the random error is invariant from case to case (Nkemdirim 1969). This might be expected since the exposure of the gauges at all stations was almost identical. Consequently, random error may be ignored when comparing the error factor in the events.

The second type of error is systematic. Rodda (1969) considered this source of error to be relatively small where site conditions are favourable. Among the major factors contributing to systematic error are a) low network density, b) inadequate exposure of gauges and c) evaporation from the gauge. In locating the gauges, care was taken to adhere very strictly to standards established by

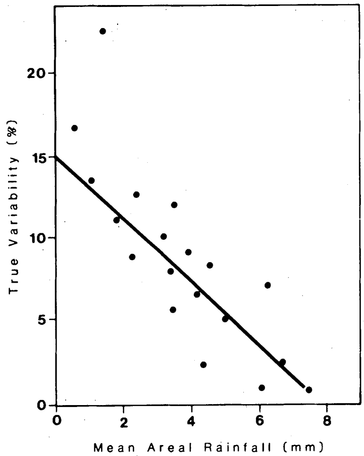

Fig. 4. Relationship between variability and rainfall amount.

WMO (1974) for gauge exposure. Evaporation was controlled by introducing a thin film of oil into the gauge. These measures allowed us to assess the systematic error due to network density by observing the reduction in total error as the gauge density was progressively increased.

Fig. 3 shows that there is incremental improvement in the systematic error with increasing rain gauge density. That improvement measured by the change in the slope of the standard error/gauge density curve almost vanished in all test cases at a density of approximately 3 gauges/km^2. It is assumed therefore that for the watershed 3 gauges/km^2 would practically eliminate this type of error in the Coal Mountain basin.

The third error type represents the 'true variability' inherent in the storm. Its numerical value is given by the standard error corresponding to a gauge density of approximately 3 gauges/km^2. For events 2 through 6 (Fig. 3) the true variability ranged from about 5 to 15 percent, with an apparent inverse relationship between the size of the variability and rainfall amount. Fig. 4 which includes additional data from subsequent experiments in the watershed shows that the relationship between variability and depth of rainfall is linear.

Case 6 is anomalous because it bulks the trend. It is relatively a large storm and its duration is about average. Yet, the standard error is the largest of the six test cases. This discrepancy may be due to characteristics of the storm not investigated in the experiment. However, the shape of curve 6 is consistent with all others, demonstrating that similar error reduction would occur with increasing gauge density.

Conclusion

The preceeding analyses demonstrate a method for assessing the 'true' variability of small rainfall events in a mountainous watershed. They show that for the watershed in question variabilities commonly range from 5 to 15 percent for such events. They also underscore the need for a large number of gauges if true variability is to be accurately assessed. Since gauge densities of the type used in this investigation far exceed the practical limits of conventional regional networks (WMO 1974) care must be exercised when interpreting rainfall variability determined from regional networks.

References

Burns, J.L. (1953) Small scale topographic effects on precipitation distribution in San Dimas Experimental Forest. *EOS, Trans. Amer. Geophy. Union, 34,* 761-768.

Eagleson, P.S. (1967) Optimum density of rainfall networks. *Water Resources Research, 3,* 1021-1033.

Lee, C.H. (1911) Precipitation and altitude in the Sierra. *Month. Weather Rev., 39,* 1092-1099.

Nkemdirim, L.C. (1970) Isolation of random errors from periodic rainfall. *Water Resources Bull., 6,* 767-774.

Nkemdirim, L. C. (1981) Extra urban and intra urban rainfall enhancement. *Water Resources Bull., 17,* 164-171.

Price, R., and Evans., R.B. (1937) Climate of the Wasatch Plateau in Central Utah. *Mon. Weather Rev., 65,* 291-301.

Rodda, J.C. (1969) The assessment of precipitation, *Introduction to Physical Hydrology.* Chap 3.1 (ii), ed. J.R. Chorley. Methuen.

Spreen, W.D. (1947) A determination of the effect of topography upon precipitation. *EOS, Trans. Amer. Geophy. Union, 28(2),* 285-290.

World Meteorological Organisation (1974) *Guide to hydro-meteorological practices,* 3rd ed. W.M.O., No. 168, Tech. Paper 82.

First received: 12 April, 1982
Revised version received: 29 September, 1982

Address:
Lawrence C. Nkemdirim,
Department of Geography,
University of Calgary,
Calgary, Alta T2N 1N4,
Canada

Brian D. Meller,
Monenco Consultants Ltd.,
Calgary, Alta T2G OP6,
Canada.